Space-VLBI with RadioAstron

pushing the limit of angular resolution in the radio band

Gabriele Bruni
Max Planck Institute for Radioastronomy

AGN 11, Trieste 23-26/09/2014

ASTRO SPACE CENTER

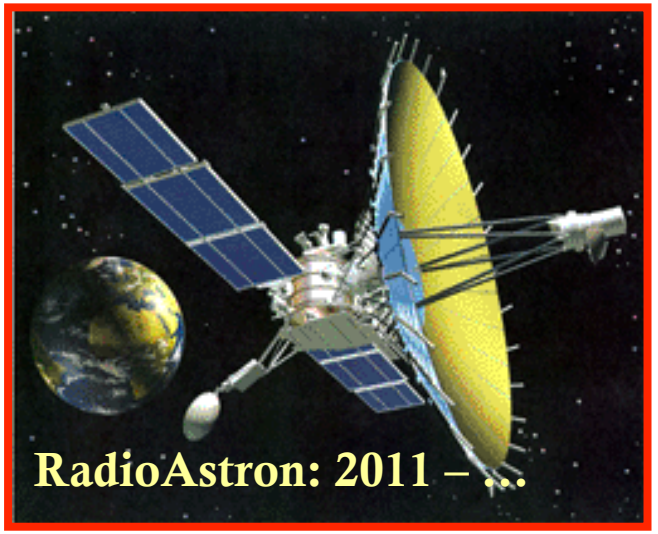
Max-Planck-Institut für Radioastronomie

Very Long Baseline Interferometry from space

1986-88

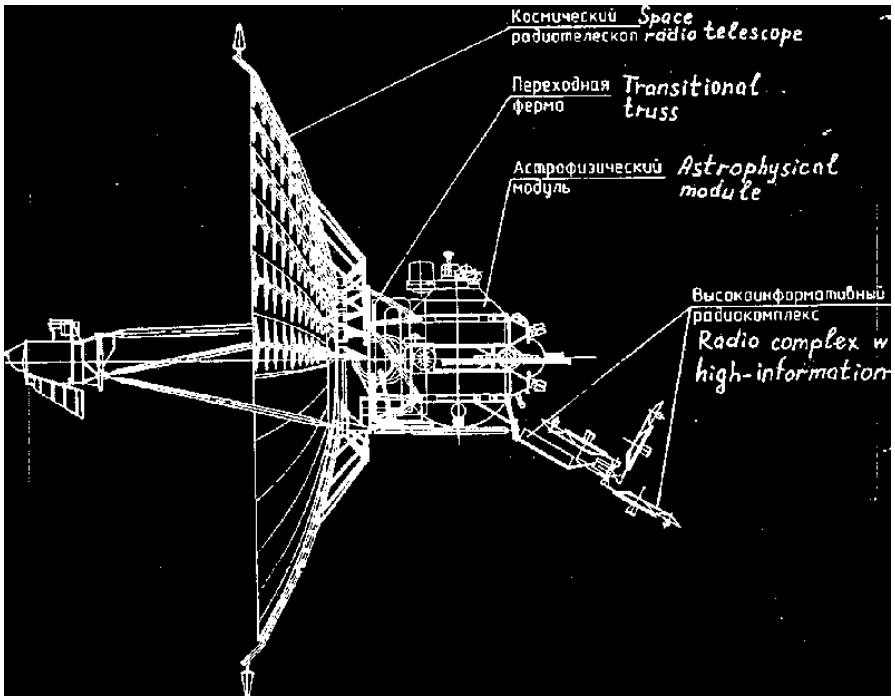
1990s

2010s



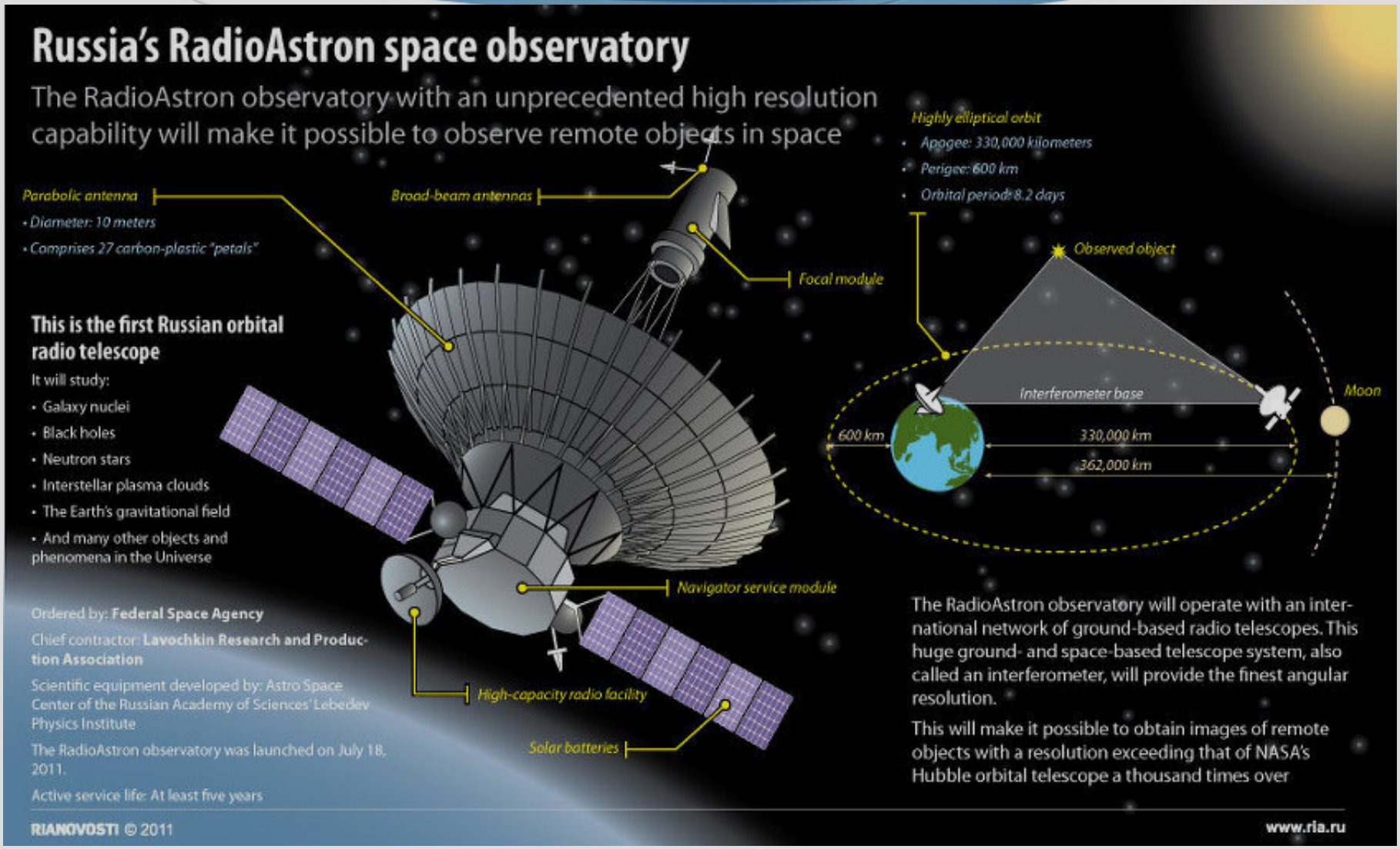
The mission

- ✓ 10-m orbiting parabola
- ✓ Launched on 18th July 2011, 5 years life-cycle. Operated by Astro-Space Center (Moscow, RU)
- ✓ 3.3 Tons
- ✓ Orbital period ~9 days (apogee 330.000 Km, perigee 600 km)
- ✓ 4 observing bands (P, L, C, K)

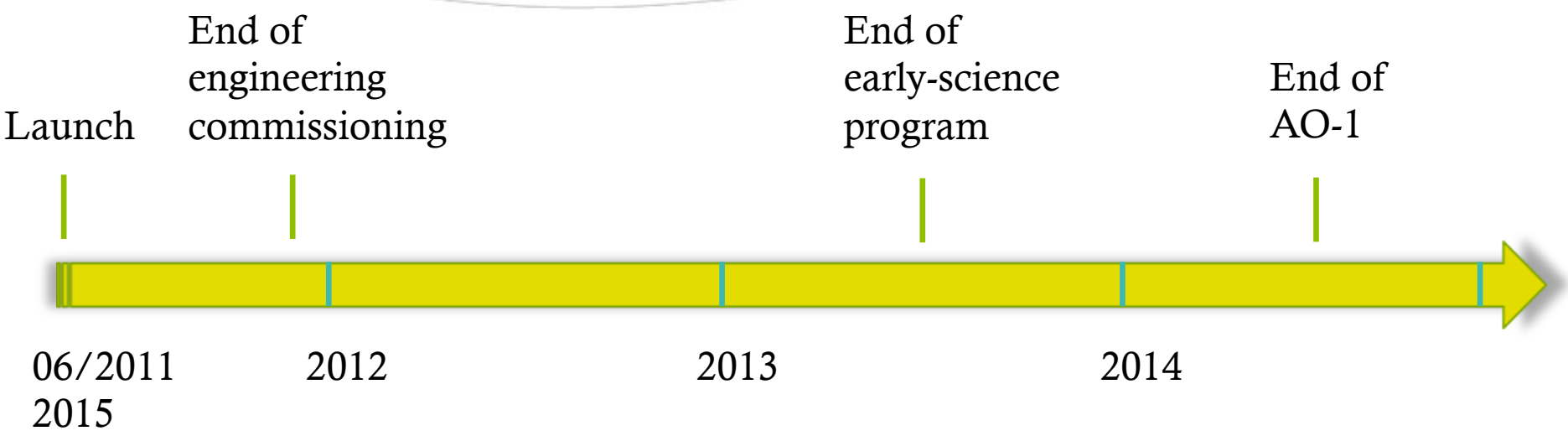


Observing Bands (cm)	Frequency range (MHz)	Bandwidth per polarization (MHz)	Smallest spacing (μas)	SEFD (kJy) LCP;RCP	Gain (mK Jy^{-1})	1σ baseline sens. (mJy) LCP; RCP
92 (P)	316 – 332	1 × 16	530	13.3; 13.5	11	14; 14
18 (L)	1636 – 1692	2 × 16	100	2.76; 2.93	15	3; 3
6 (C)	4804 – 4860	2 × 16	35	11.6; —	13	5; —
1.3 (K)	18372 – 25132	2 × 16	7	46.7; 36.8	3	17; 15

The mission


Russia's RadioAstron space observatory
The RadioAstron observatory with an unprecedented high resolution capability will make it possible to observe remote objects in space
Parabolic antenna
• Diameter: 10 meters
• Comprises 27 carbon-plastic "petals"
Broad-beam antennas
Focal module
Navigator service module
High-capacity radio facility
Solar batteries
This is the first Russian orbital radio telescope
It will study:
• Galaxy nuclei
• Black holes
• Neutron stars
• Interstellar plasma clouds
• The Earth's gravitational field
• And many other objects and phenomena in the Universe
Ordered by: Federal Space Agency
Chief contractor: Lavochkin Research and Production Association
Scientific equipment developed by: Astro Space Center of the Russian Academy of Sciences' Lebedev Physics Institute
The RadioAstron observatory was launched on July 18, 2011.
Active service life: At least five years
Highly elliptical orbit
• Apogee: 330,000 kilometers
• Perigee: 600 km
• Orbital period: 8.2 days
Observed object
Interferometer base
Moon
600 km
330,000 km
362,000 km
The RadioAstron observatory will operate with an international network of ground-based radio telescopes. This huge ground- and space-based telescope system, also called an interferometer, will provide the finest angular resolution.
This will make it possible to obtain images of remote objects with a resolution exceeding that of NASA's Hubble orbital telescope a thousand times over
RIANOVOSTI © 2011
www.ria.ru

The mission



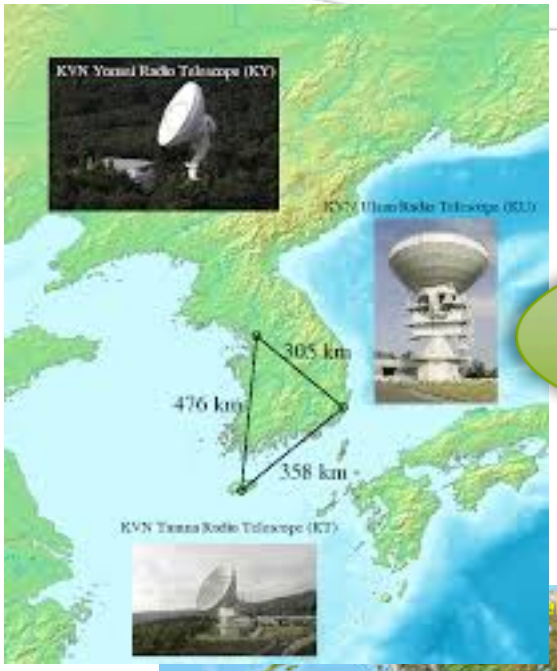
- Different WGs for AGNs, pulsars, and masers.
- Mainly KSPs in AO-1, both individual PI and KS Projects in AO-2
- Planned 50% PI and 50% KS Projects after AO-2

The ground segment

Different stations are needed for satellite operations and observations:

- ✓ Control Stations: operates the satellite
- ✓ Laser Ranging Stations: track satellite position → Orbit reconstruction
- ✓ Tracking Stations: receive satellite data (Pu, Gb)
- ✓ Ground Radio Stations: observe in conjuction with RadioAstron
- ✓ Ground Facilities: Ballistic center for orbit reconstruction; Correlation centers for data processing; dedicated lines for fast e-transfer of large amount of data

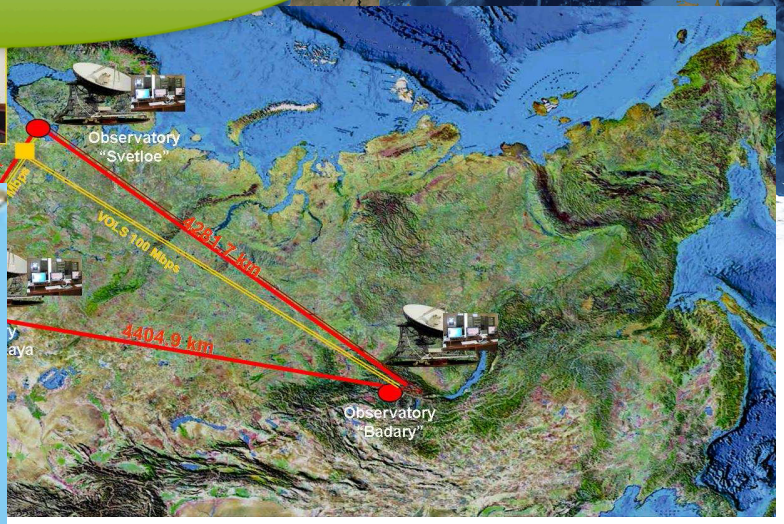
The ground segment



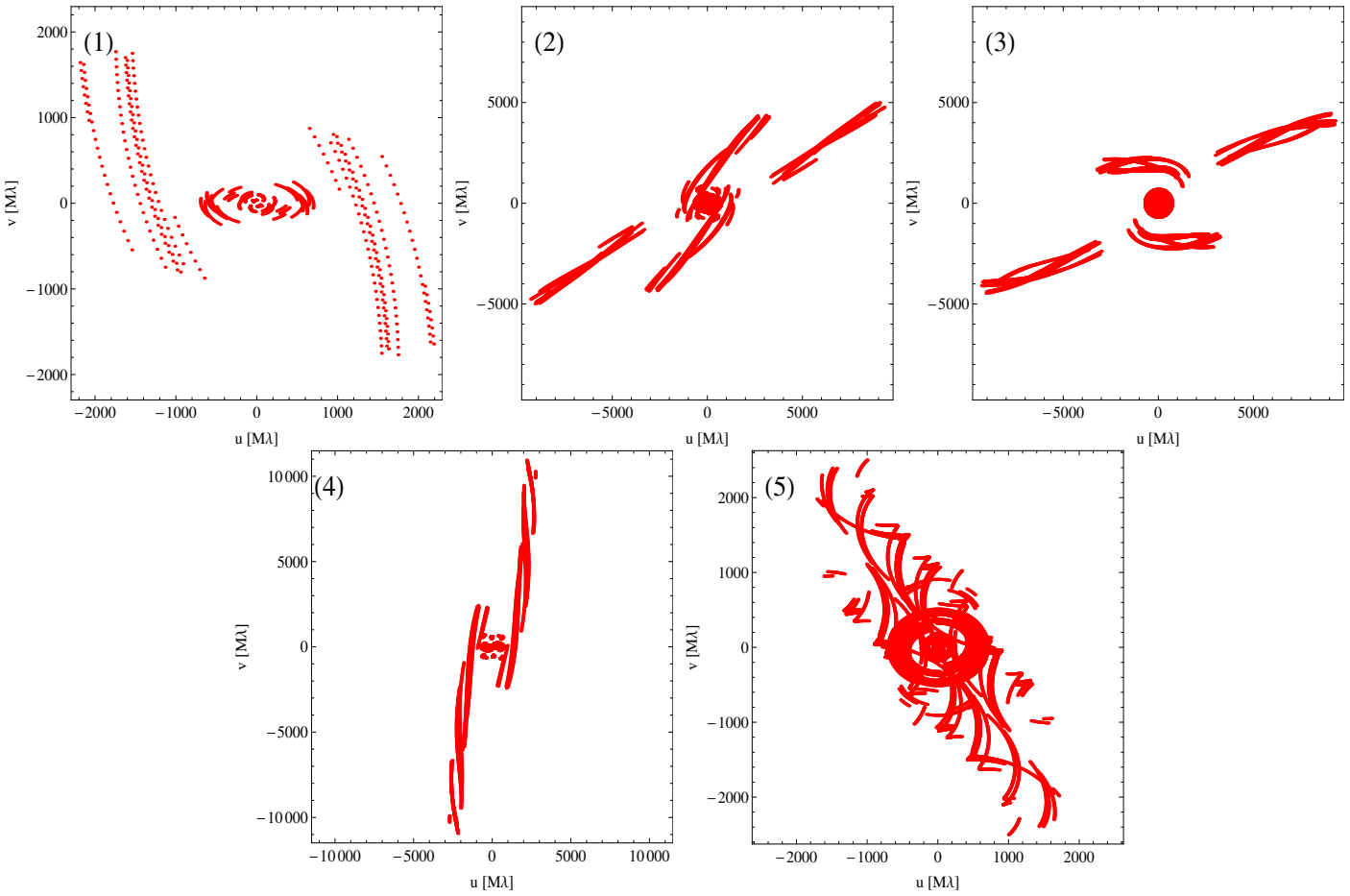
EUROPEAN VLBI NETWORK

JIVE JOINT INSTITUTE FOR VLBI IN EUROPE

More than 20 stations per scan!



The ground segment



The Correlation

Four correlators are processing RadioAstron data:

- ASC software FX-correlator: AGN survey, Russian PIs projects
- Bonn DiFX software correlator: upgraded version of the DiFX to correlate space-based antennas. AGN imaging projects
- JIVE SFXC software correlator: mainly pulsar projects
- CURTIN University correlator: Cen A imaging project (Australia)

KSPs at MPIfR

- Structure of compact jets in strong AGN (*AGN-S*)

M. Perucho, A.P. Lobanov, T. Savolainen, T.B. Muxlow, I. Agudo, J.M. Anderson, U. Bach, R. Beswick, R. Davis, P. Edwards, J.A. Eilek, C.M. Fromm, S.T. Garrington, J.L. Gómez, P.E. Hardee, Y.Y. Kovalev, T.P. Krichbaum, S.-S. Lee, J.M.Martí, D.L.Meier, P. Mimica, E. Ros, F. Schinzel, K. Sokolovsky, P. Wilkinson, J.A. Zensus

- Nearby AGN at scales of 5—500 gravitational radii (*AGN-N*)

T. Savolainen, G. Giovannini, K. Hada, S. Tingay, T.P. Krichbaum, A. Lobanov, M. Orienti, J.M. Anderson, U. Bach, B. Boccardi, C. Casadio P. Edwards, J. Eilek, C.M. Fromm, M. Giroletti, P. Hardee, Y. Hagiwara, M. Honma, M. Kino, Y.Y. Kovalev, S.-S. Lee, D.L. Meier, H. Nagai, S.P. O'Sullivan, C. Reynolds, F. Schinzel, B.W. Sohn, K.V. Sokolovsky, J.A. Zensus

- Polarization and magnetic fields in compact jets (*AGN-P*)

J. L. Gómez, A. P. Lobanov, I. Agudo, A. Alberdi, J. M. Anderson, U. Bach, M. Bell, S. Bernhart, C. Casadio, T. V. Cawthorne, E. Clausen-Brown, J. Eilek, C. Fromm, D. Homan, S. G. Jorstad, M. Keck, Y. Y. Kovalev, T. P. Krichbaum, S. S. Lee, A. P. Marscher, J. M. Mart, S. Molina, K.-I. Nishikawa, M. A. Perez Torres, M. Perucho, E. Ros, T. Savolainen, B. W. Sohn, K. V. Sokolovsky, G. B. Taylor, J. A. Zensus

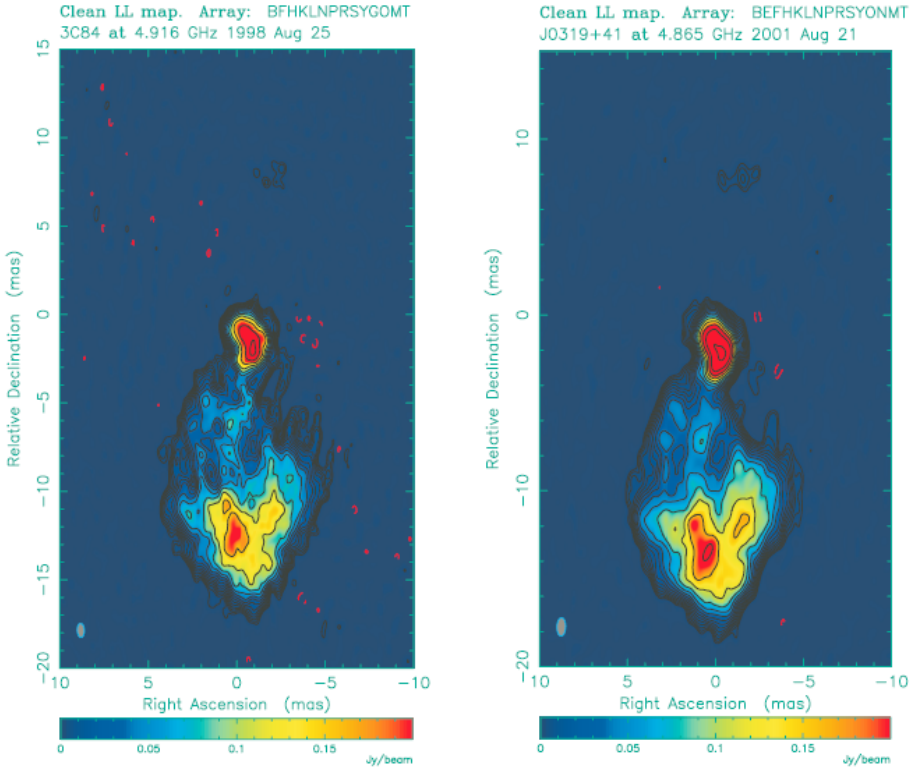
KSPs at MPIfR

- Formation of relativistic jets. Energy release in jets and role of EM component in jets:
  - ***AGN polarization, strong AGN.***
- Direct detection and imaging of radio emission from accretion disks and SMBH vicinity:
  - ***nearby AGN, AGN polarization.***
- Connection between jet continuum radiation and various constituents of AGN, including BLR, NLR, and sub-relativistic flows:
  - ***strong AGN, nearby AGN.***

Nearby AGNs

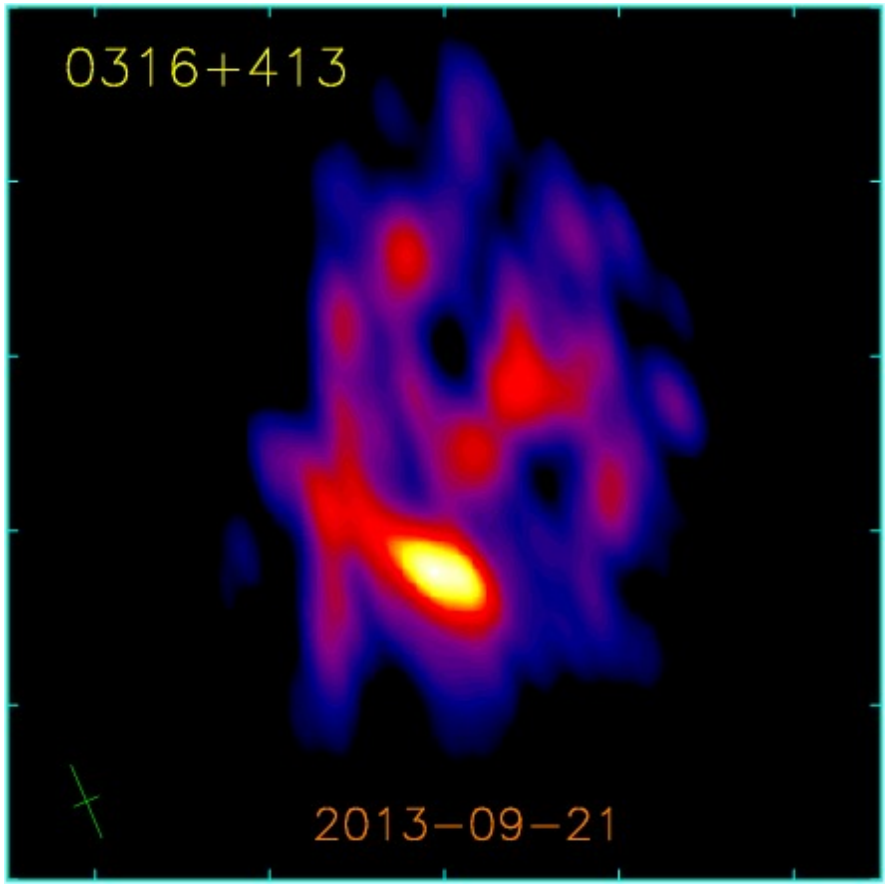
VSOP observations by Asada et al. (2006)

Resolution of 0.78x0.39 mas at 5GHz

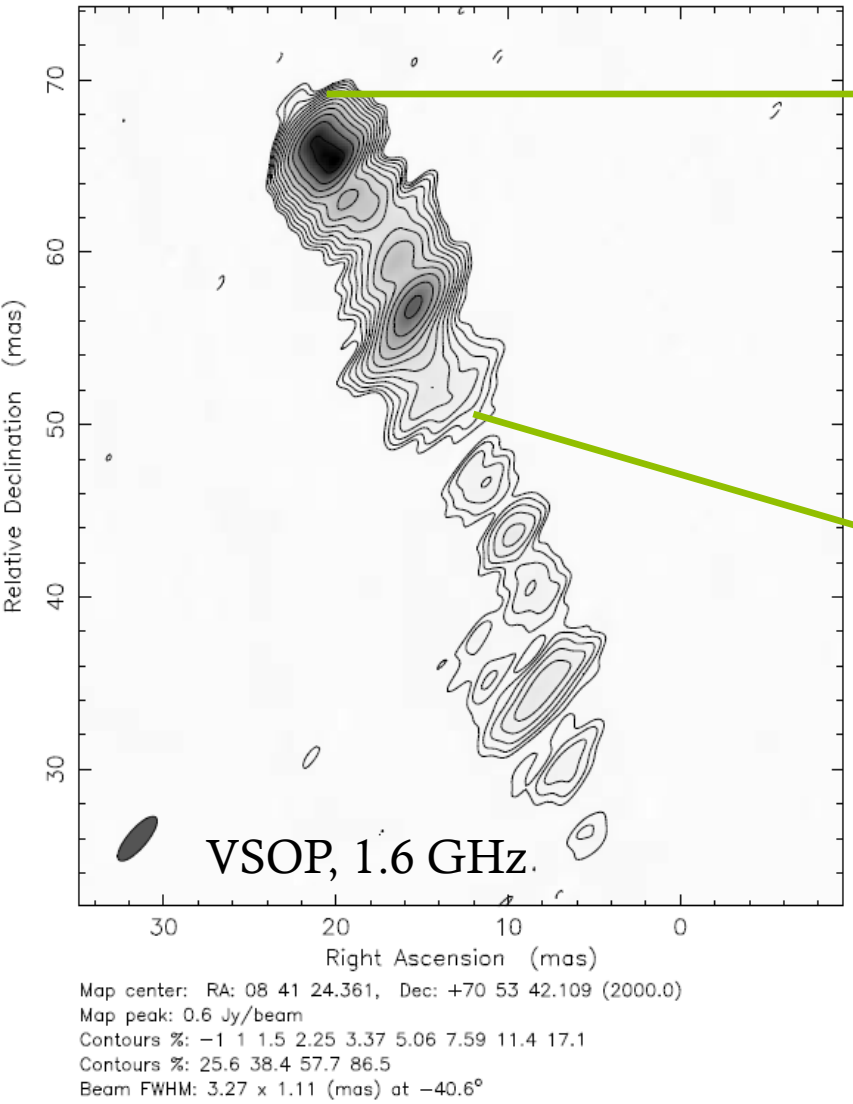


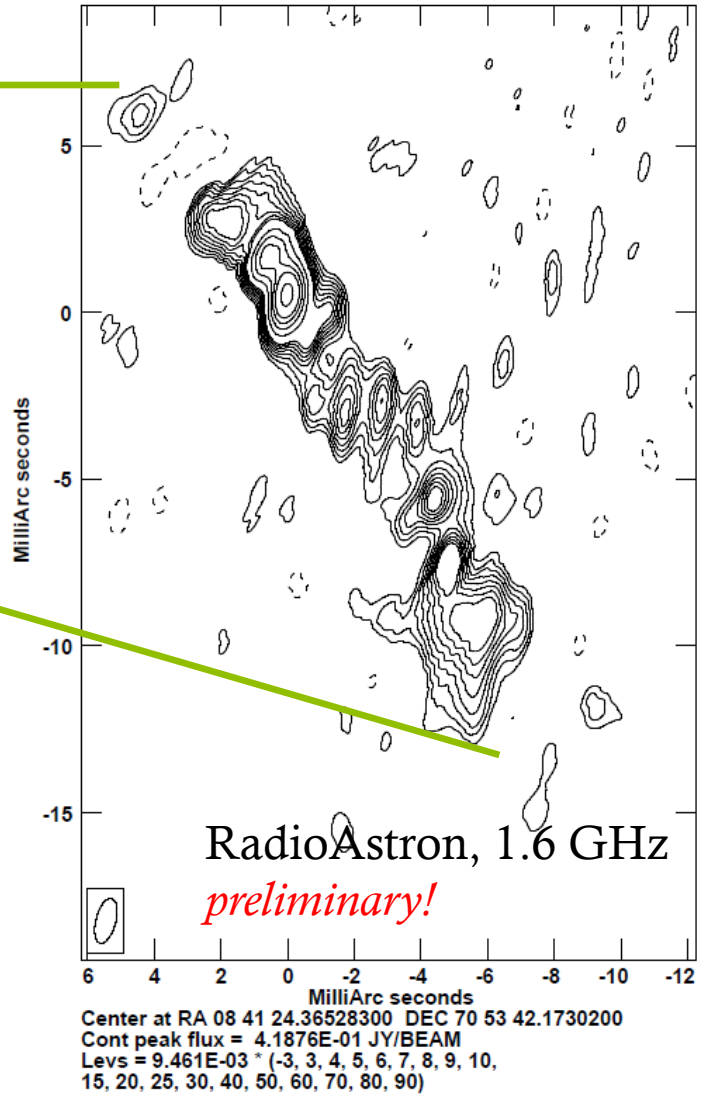
RadioAstron by Savolainen et al. (2013)

resolution of 0.45x0.15 mas at 5GHz

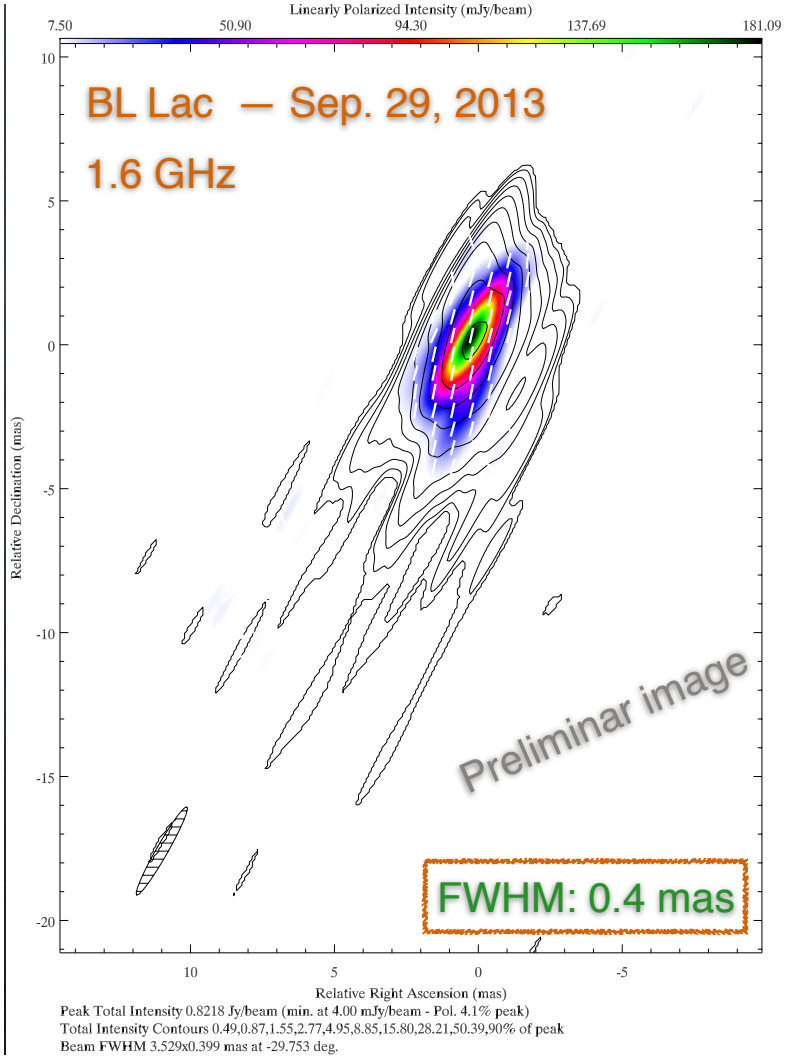


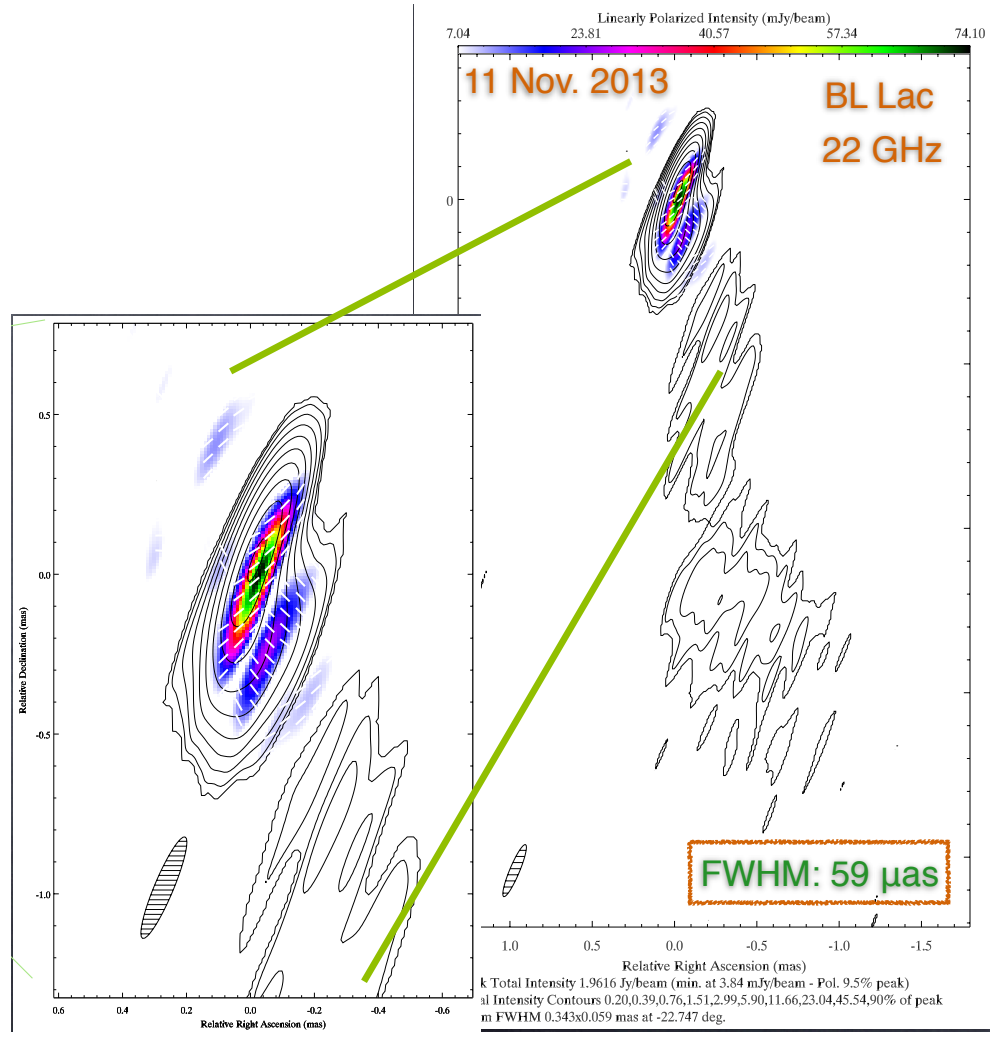
Strong AGNs


Relative Declination (mas)
70
60
50
40
30
30
20
10
0
Right Ascension (mas)
VSOP, 1.6 GHz.
Map center: RA: 08 41 24.361, Dec: +70 53 42.109 (2000.0)
Map peak: 0.6 Jy/beam
Contours %: −1 1 1.5 2.25 3.37 5.06 7.59 11.4 17.1
Contours %: 25.6 38.4 57.7 86.5
Beam FWHM: 3.27 x 1.11 (mas) at −40.6°

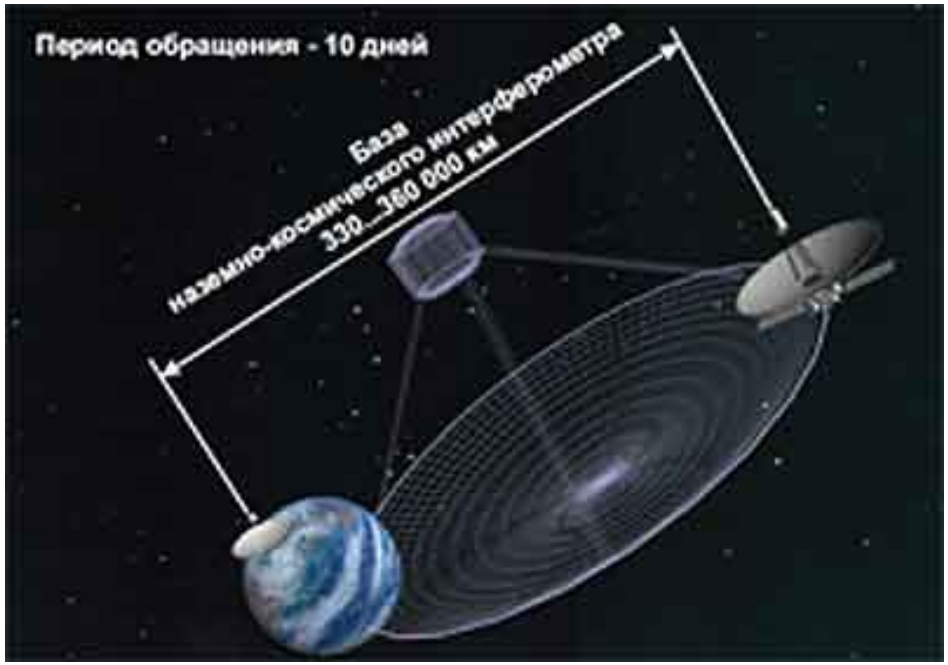

MilliArc seconds
5
0
-5
-10
-15
6
4
2
0
-2
-4
-6
-8
-10
-12
MilliArc seconds
RadioAstron, 1.6 GHz
preliminary!
Center at RA 08 41 24.36528300 DEC 70 53 42.1730200
Cont peak flux = 4.1876E-01 JY/BEAM
Levs = 9.461E-03 * (-3, 3, 4, 5, 6, 7, 8, 9, 10,
15, 20, 25, 30, 40, 50, 60, 70, 80, 90)

Polarisation in AGNs





More results coming from AO-2 and AO-3…..



….. Stay tuned!